



# **Physics Data Needs for Proton Radiography**

## **Fermilab Director's Review of the MIPP Run Plan**

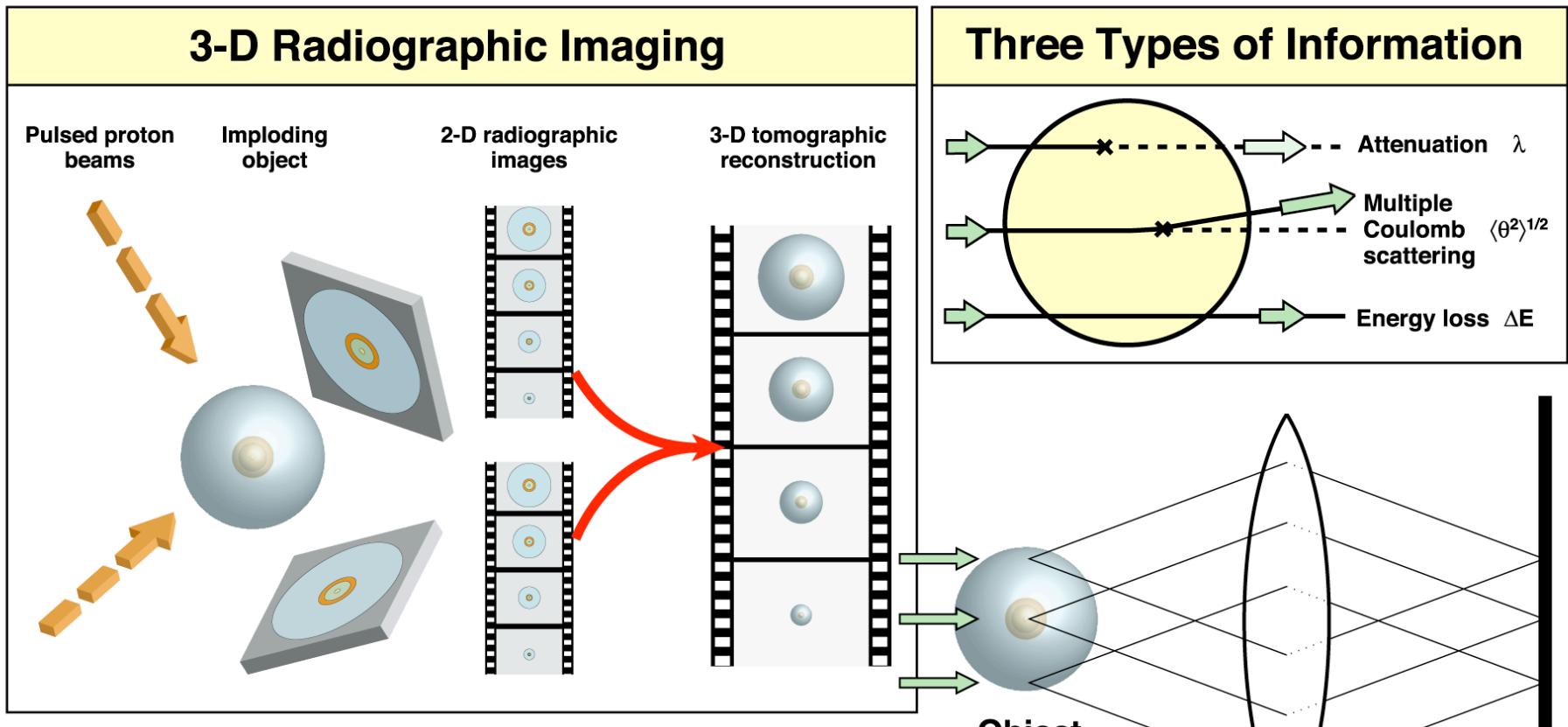
November 10, 2004

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N Division, Physics and Advanced Technology  
Lawrence Livermore National Laboratory



# What Is Proton Radiography?

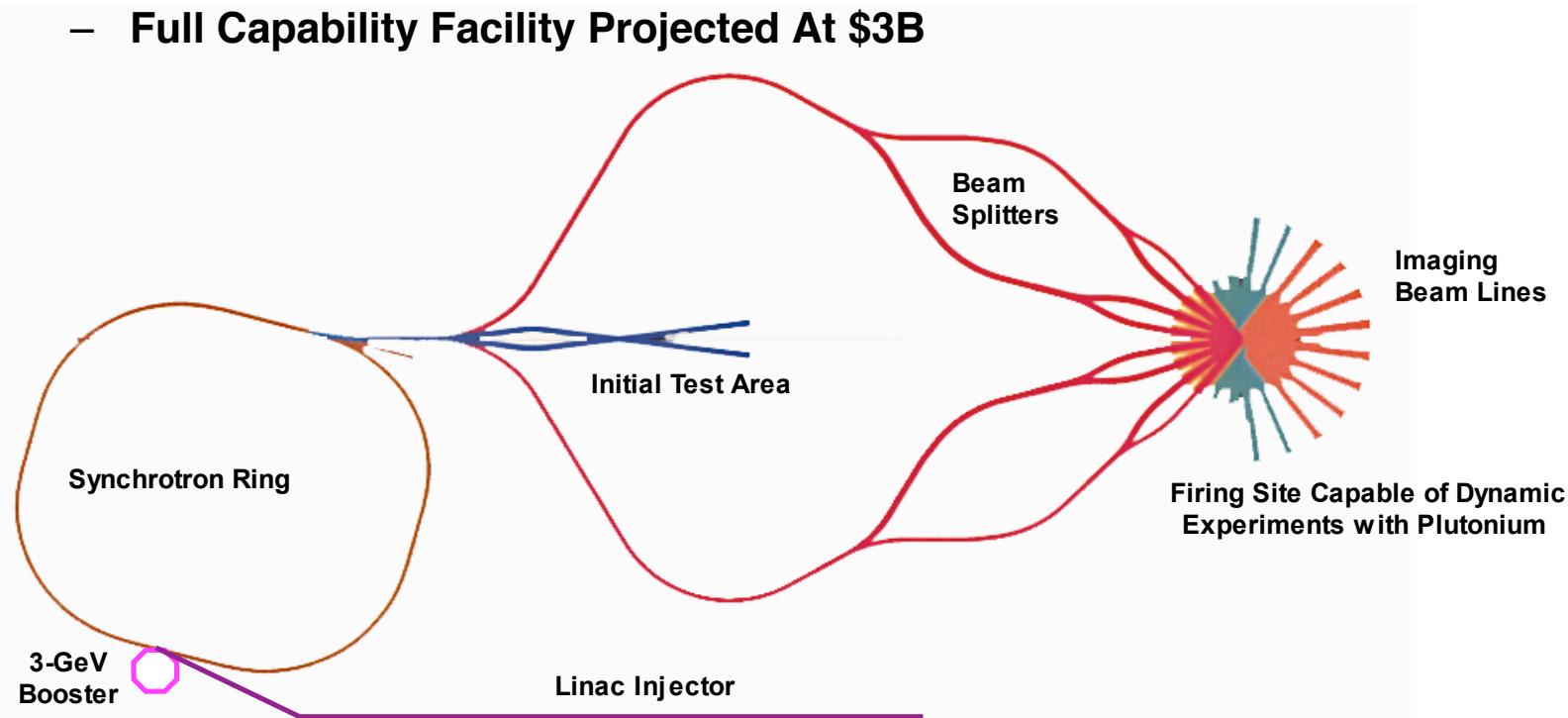


- Protons can provide multiple pulses in time
- Protons can provide material identification information
- No issues with conversion — either at target or in detector

# Advanced Hydrotest Facility Concept

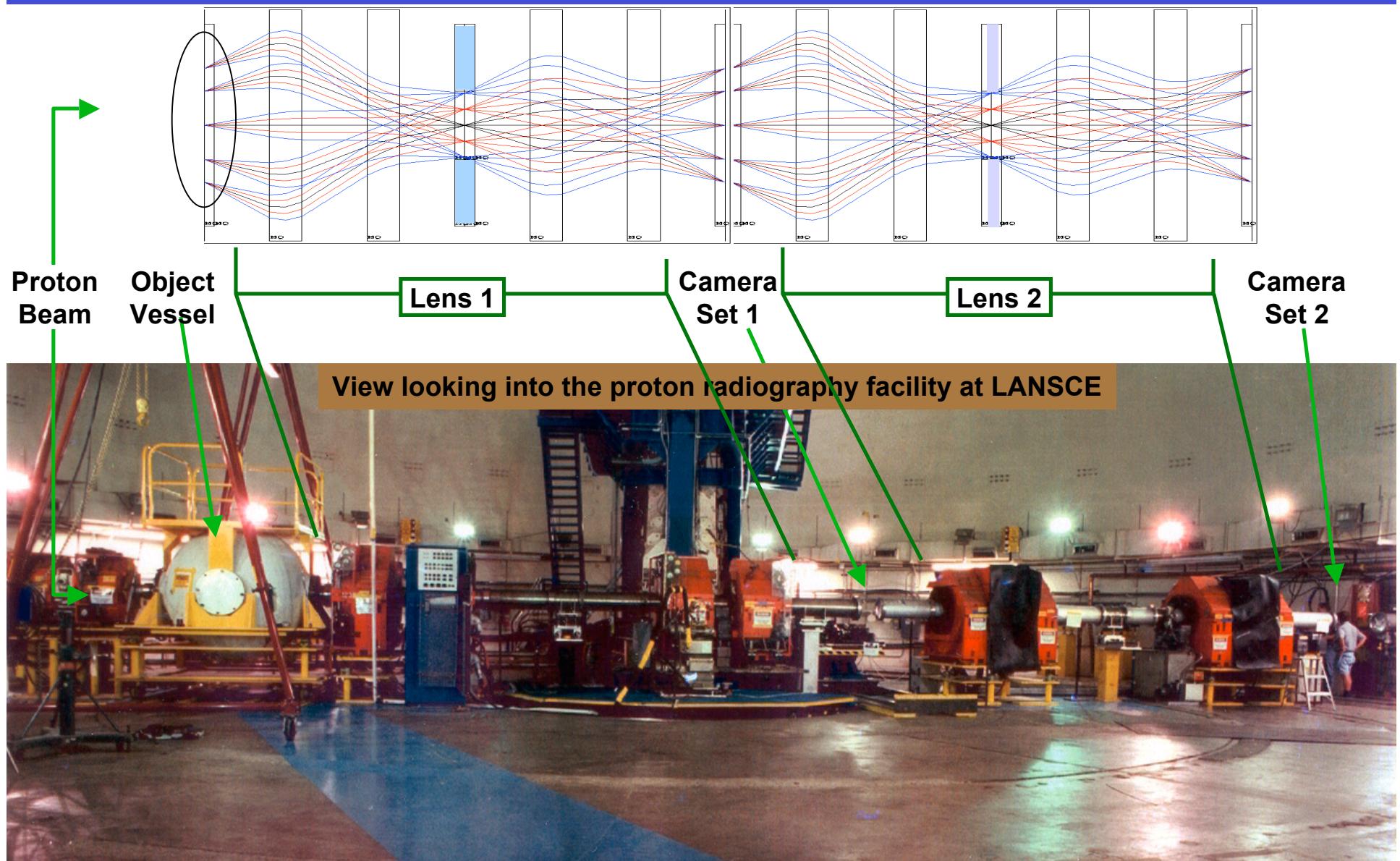


- Stockpile Stewardship Needs Higher Precision Quantitative Radiography
  - Multi-Axis, Multi-Frame, SNM
  - 1% Density Measurement
- Proton Radiography Has Become The Technology of Choice
  - 50 GeV/c,  $10^{12-13}$  protons, 12 axes, 10-20 time frames
  - Full Capability Facility Projected At \$3B



# Forming An Image With Magnetic Lenses

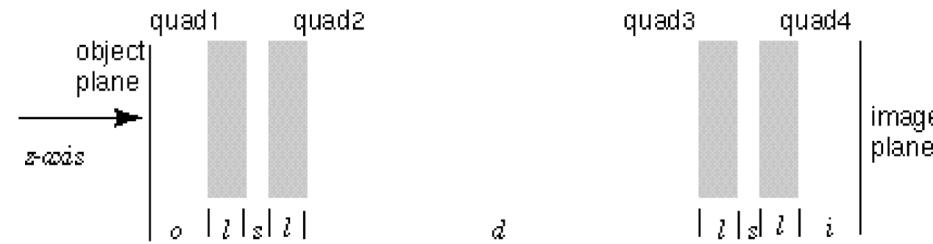
## LANL LANSCE Line C



# Lens Chromatic Dependence Leads to Blur



- Some of these will be transmitted by the lens/collimator and be detected
- First order momentum dependence of quadruplet lens



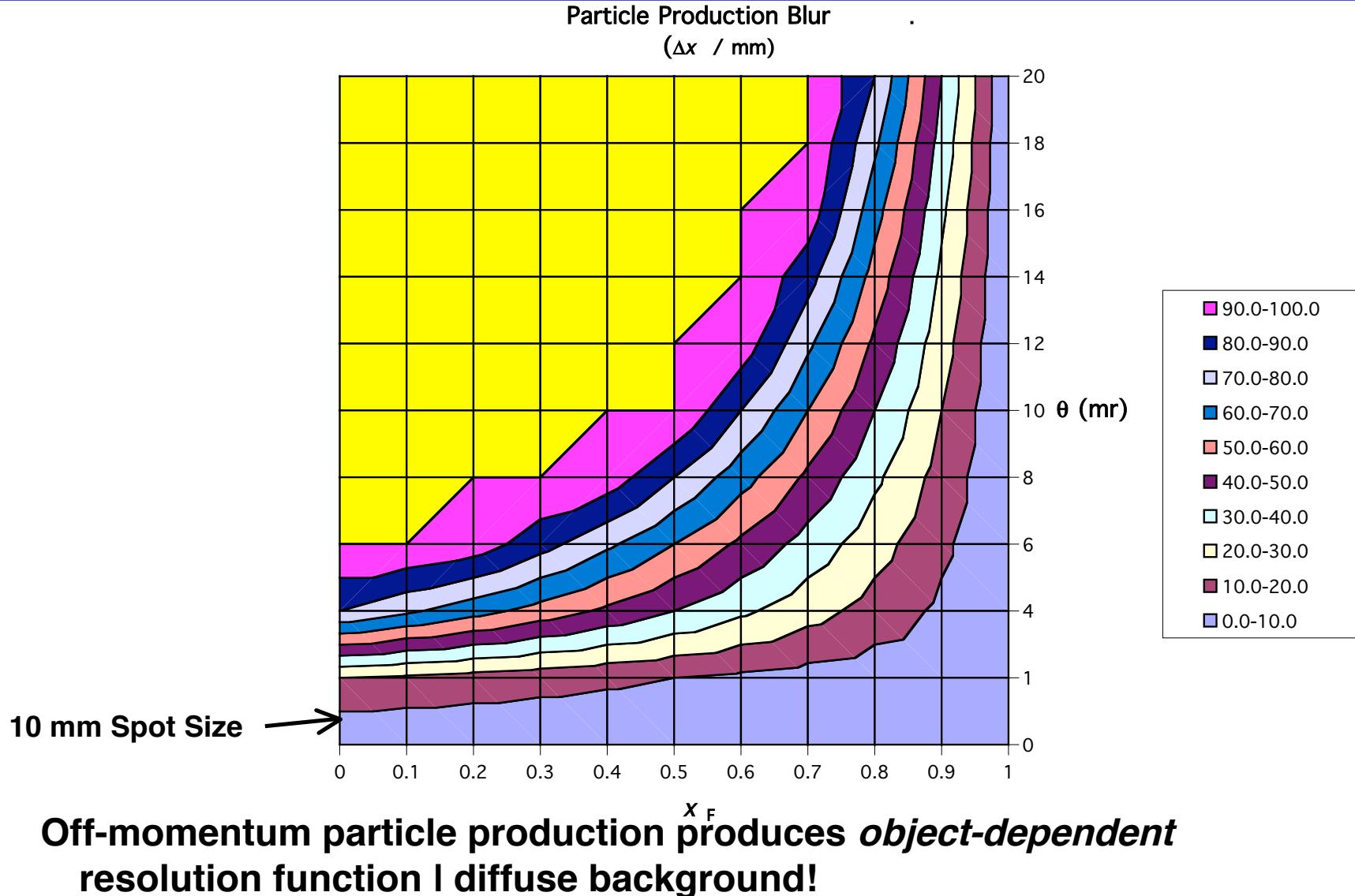
$$\begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix} = 4 \frac{\Delta p}{p} \begin{pmatrix} 1 - 2i/d & o + i - 2i/d \\ -2/d & 1 - 2o/d \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

- Assume a symmetric lens ( $o = i = d/2 = 5$  m)

$$\begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix} = (1 - x_F) \begin{pmatrix} 20 \text{ mm} \frac{x'_0}{\text{mr}} \\ 0.8 \text{ mr} \frac{x_0}{\text{mm}} \end{pmatrix}$$



# Consider Just the Blur Term

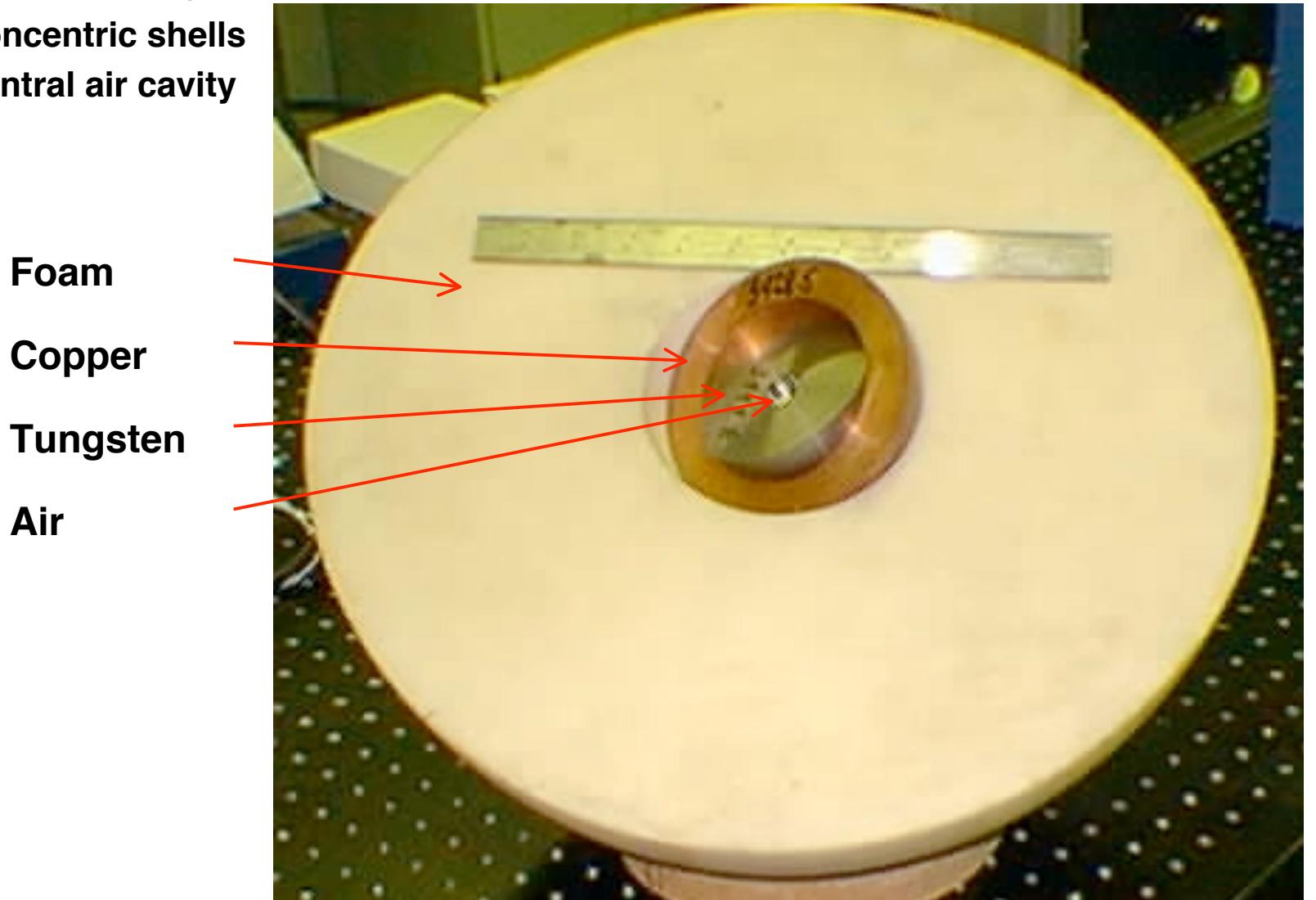


# Does Chromatic Blur Matter In Real Experiments?



- **French Test Object (FTO)**

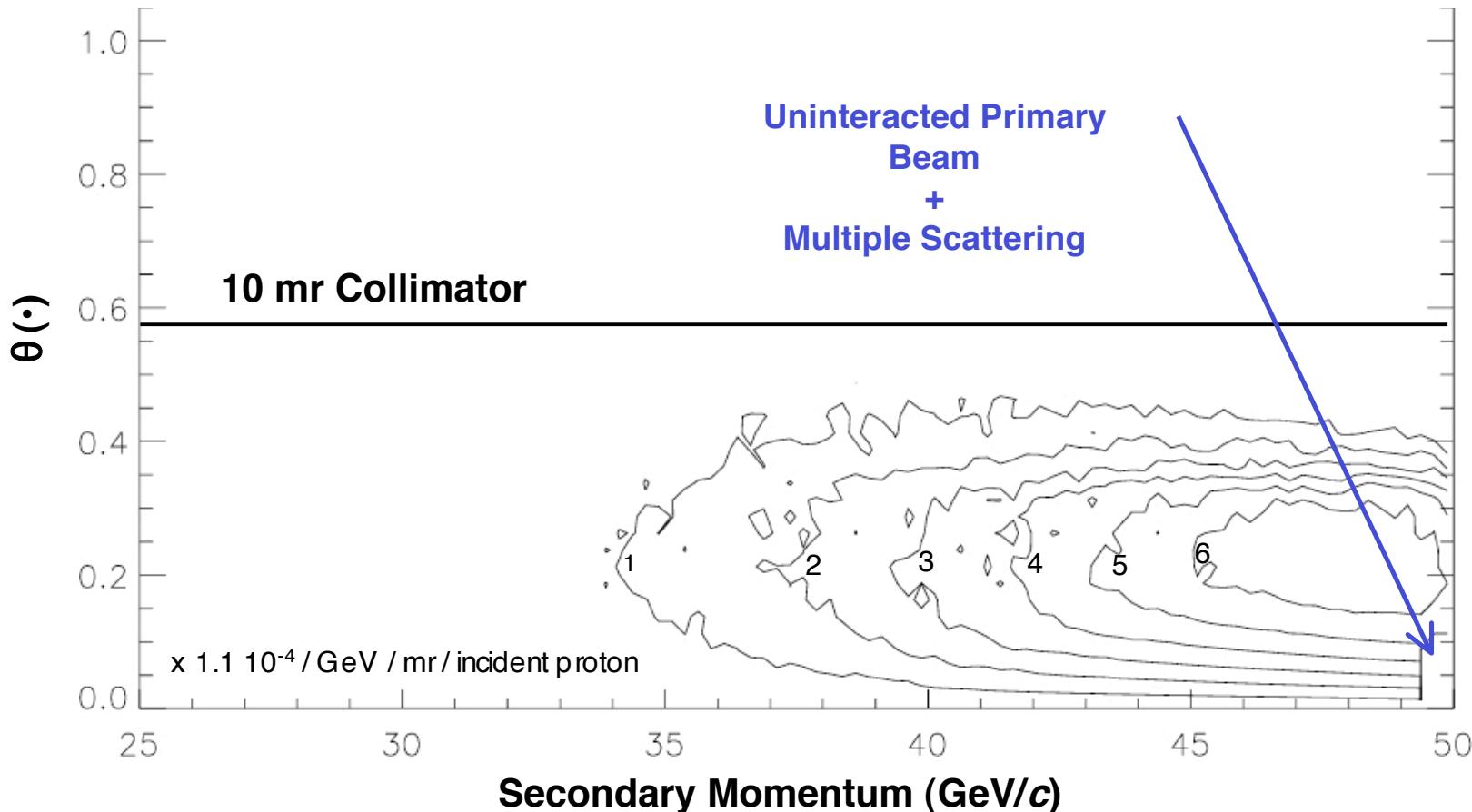
- Concentric shells
  - Central air cavity



# Phase Space of Particles Produced in the FTO



- 50 GeV/c proton beam
- Use Malensek particle production model
- Compute transmission through FTO and scaled E933 lens



# MINOS Particle Production Phase Space

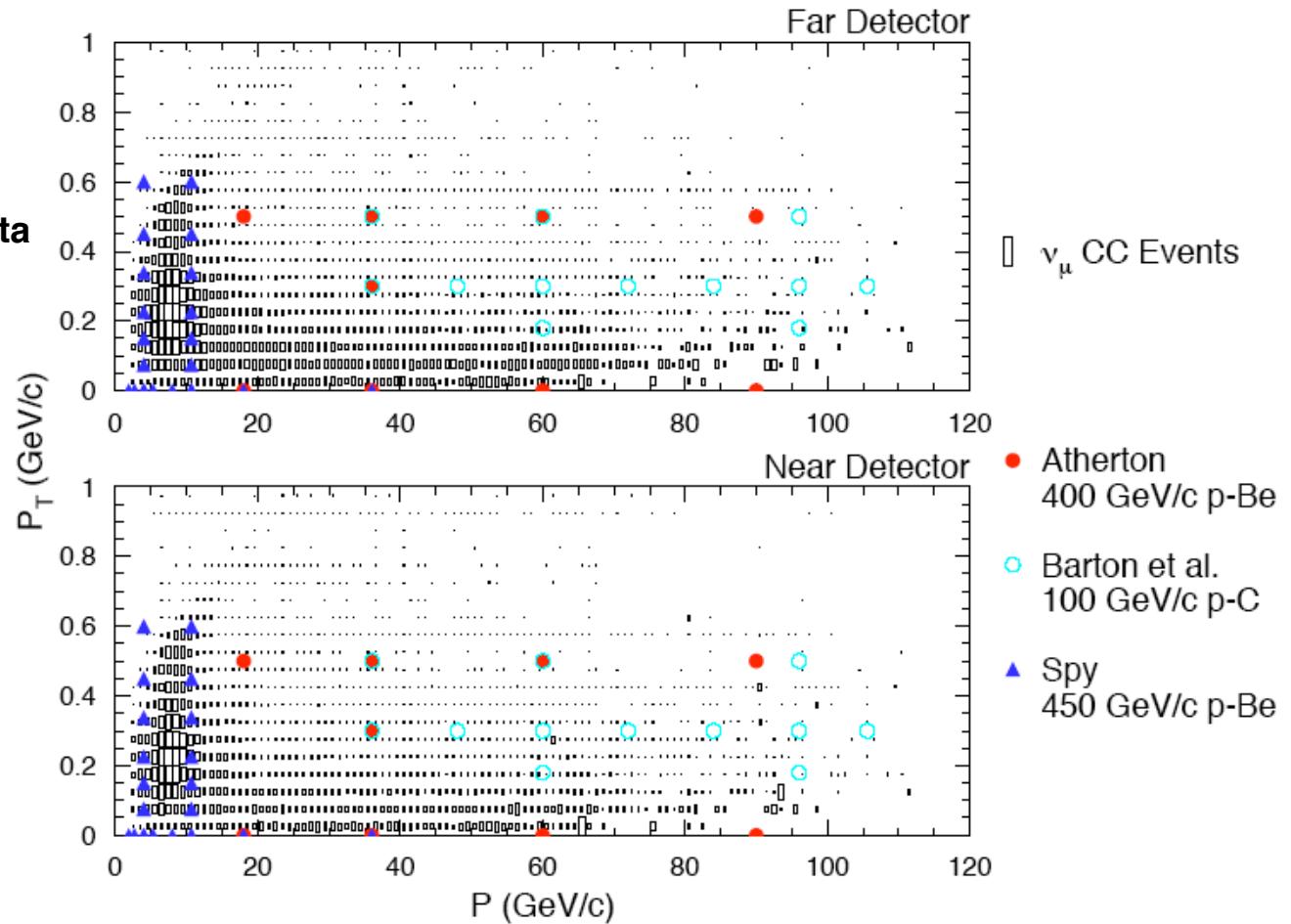


- **Legend**

- **Colored points:**  
particle production data
- **Boxes:**  
MINOS  $\nu$  acceptance

- **Ratio Measurement**

- Numerator  
Far Detector (top)
- Denominator  
Near Det. (bottom)  
x Ratio Prediction



- Only relevant measurements are
  - 100, 400, 450 GeV; NuMI is 120 GeV.
  - Be and C; NuMI is C target.

# Comparison of NuMI/MINOS to pRad

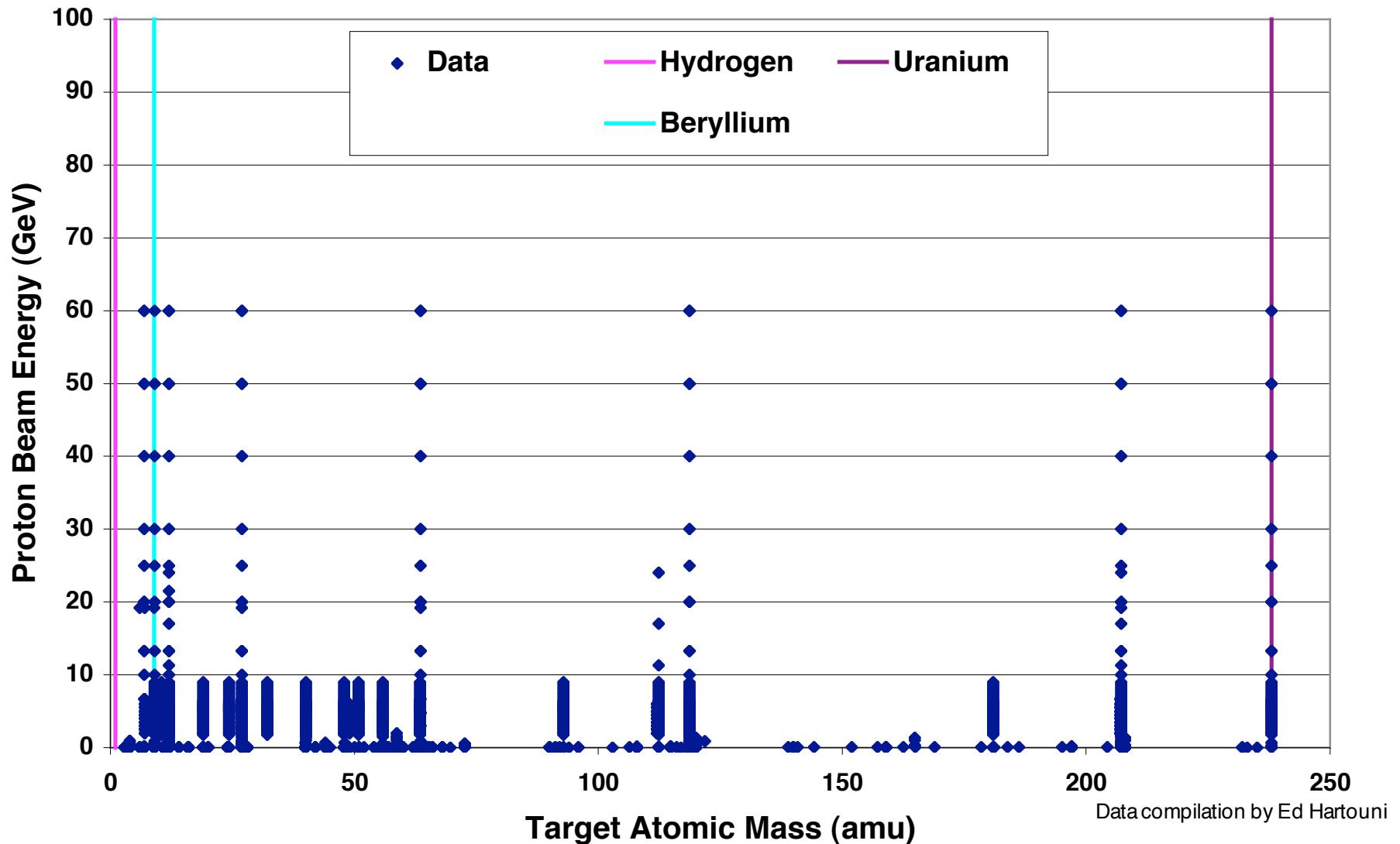


	<b>Experiment</b>	
	<b>NuMI / MINOS</b>	<b>pRad AHF</b>
<b>Beam</b>	<b>120 GeV/c</b>	<b>~ 50 GeV/c</b>
<b>Target Material</b>	<b>C</b>	<b>H-U</b>
<b>Target Thickness</b>	<b>2 <math>\Lambda</math></b>	<b>Various</b>
<b>Focusing</b>	<b>Point to Parallel</b>	<b>Point to Point</b>
<b>Detected Particle</b>	<b>Tertiary +</b>	<b>Uninteracted Primary</b>
<b>Measurement</b>	<b>Ratio of Similar Phase Space Regions</b>	<b>Ratio of Different Phase Space Regions</b>

# Relevant Data Is Sparse Even For Total Cross Section



World Proton Nucleus Data Sets



Data compilation by Ed Hartouni

# Physics Data Needed For Proton Radiography

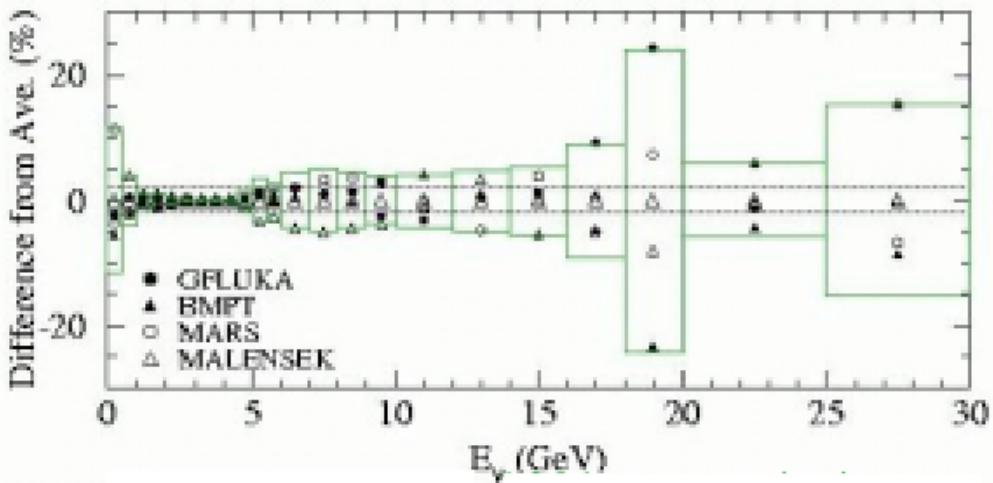
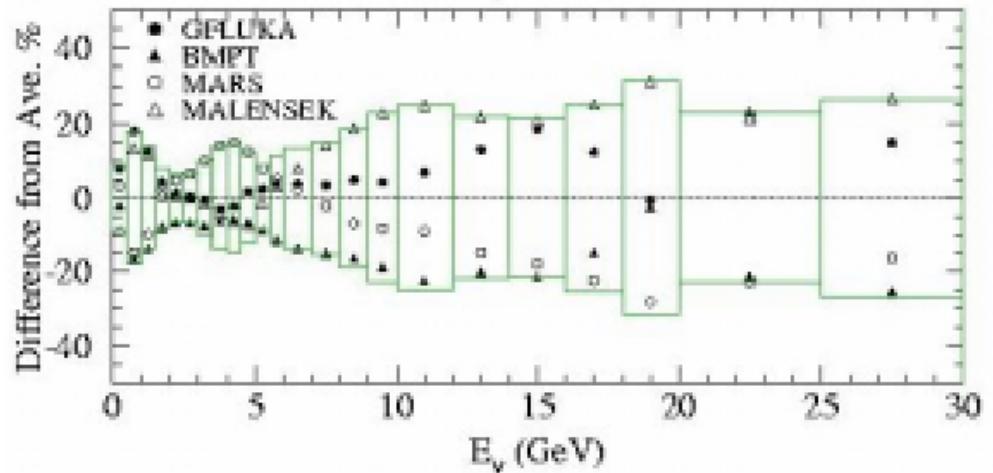


- **$A$  Scaling**
  - Verify geometric scaling for large  $A, E$
  - Direct measurements for small  $A$
- **$E$  Scaling**
  - Direct measurements for large and small  $A$
  - Enable 5% interpolations around 50 GeV/c
- **$(p, p_T)$  distributions for  $\pi, K, p$**
- **Reinteraction cross sections**
  - Need  $\pi, K, p$  beams
- **Materials directly relevant for hydrotests**
  - H, Be, C, N, Cu, Pb, DU

# MINOS Sensitivity to Particle Production Phase Space



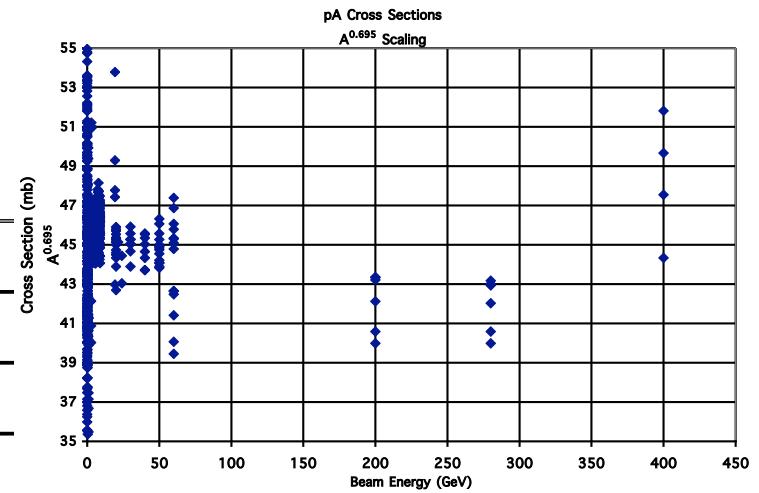
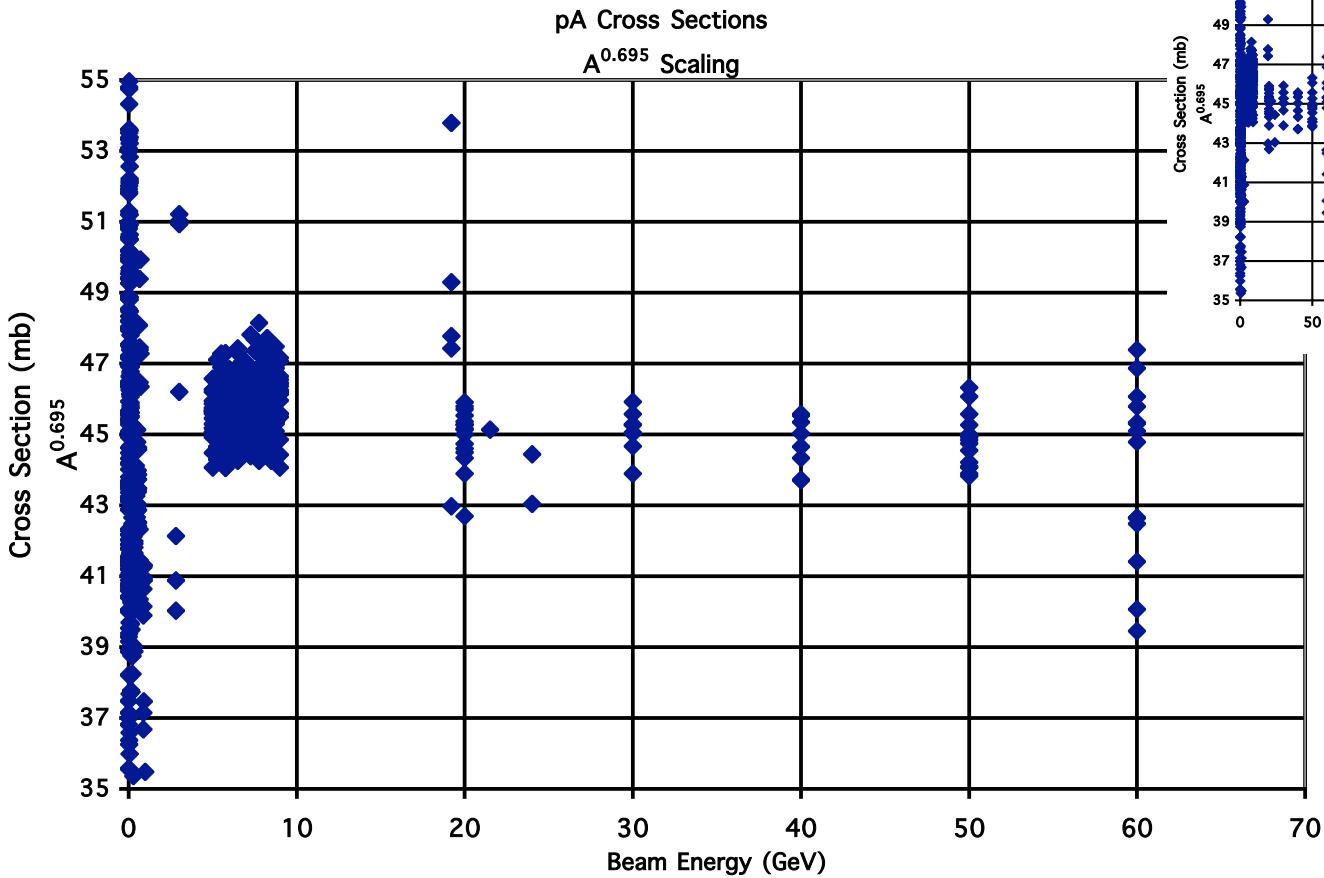
- Consider all the standard models
  - GFLUKA, BMPT, MARS, Malensek
  - Absolute flux estimates vary by 20%
- Oscillation physics is Far/Near ratio
- Use average of models
  - Introduces a 5–10% systematic error, spanning the range of likely models
- MIPP will reduce this systematic error to < 2%



# Can We Interpolate In Energy/Target?



- High energy ( $> 5$  GeV) cross sections dominated by  $A^{2/3} = 0.695$  scaling



- Residual variations with  $A, E \sim 3\%$